§2. Critical Heat Fluxes on a Flat Plate Pasted on One End of a Series Connected Rectangular Duct Containing Pressurized He II

Tatsumoto, H., Shirai, Y., Shiotsu, M. (Dept. of Energy Science & Technology, Kyoto University),
Hata, K., Hama, K. (Institute of Advanced Energy, Kyoto University)

The knowledge of heat flow in the multi-series connection of the rectangular ducts containing He II is important for the cooling design of He II cooled superconducting magnets. The purpose of this study is twofold. The first is to obtain the experimental data of steady-state heat transfer and critical heat flux (CHF) on two-series-connected rectangular ducts with different cross-sectional areas in pressurized He II for wide ranges of experimental conditions. The second is to present a CHF correlation which can describe the experimental data.

Three series connected rectangular ducts made of FRP with different cross sectional area were used. One side of the flat plate heater was attached to the end plate of the first FRP duct, and the other end of the second duct was opened to pressurized He II. All flat plate heaters made of Manganin were 10 mm in width, 40 mm in length and 0.1 mm in thickness. The first duct was Gorter-Mellink duct with the same length, L_1, of 20 mm, and the second duct had the same length, L_2, of 100 mm. The inner widths of the second duct, w_2, were 16.4 mm, 26.8 mm and 31.5 mm, respectively. Therefore, the ratio of the cross-sectional area of second duct to that of first duct, A_2/A_1, of three duct heaters was varied from 1.64 to 3.15. The steady-state CHFs were measured on three ducts with the various size of A_2/A_1 in subcooled He II at atmospheric pressure for the bulk liquid temperatures ranging from 1.8 to 2.1 K.

Figure 1 shows the relationship between critical heat flux, q_{cr}, and bulk liquid temperature, T_B, at atmospheric pressure with A_2/A_1 as a parameter. As shown in the figure, the CHF increases with the decrease in bulk liquid temperature, T_B. The values of CHF for a fixed T_B tend to increase and approach a constant value with increasing A_2/A_1. A CHF correlation for a series connected duct is derived as follows. First, it is assumed that the temperature at one end of the second duct is approximately equal to T_B, when the liquid temperature adjacent to the heated surface reaches T_λ. The temperature averaged over the cross sectional area at the boundary between the ducts would be regarded as uniform at the value T_i, which is higher than the bulk liquid temperature T_B. As the individual duct carries the same heat Q, the heat flux in the first duct, in which the temperature difference is $\Delta T=T_\lambda-T_i$, is obtained as follows based on the Gorter-Mellink equation.

$$q=\frac{Q}{A_1}=\left(\frac{1}{L_1}\int_{T_i}^{T_\lambda} f(T)^{-1}dT\right)^{1/3} \qquad (1)$$

On the other hand, the effect of the heat flow expansion from the first duct to the second duct must be considered in the second duct with $\Delta T=T_i-T_B$. Therefore, the heat flux averaged over the cross sectional area of the boundary can be described by using the CHF correlation with the effect of the heat expansion from a flat plate that has been presented by authors [1].

$$q=\frac{Q}{A_1}=\left(k_2\int_{T_B}^{T_i} f(T)^{-1}dT\right)^{1/3} \qquad (2)$$

where

$$\frac{1}{k_2}=\left\{\left(\frac{A_1{}^3L_2}{A_2{}^3}\right)^{3/2}+\left(\frac{w_1}{0.78}\right)^{3/2}\right\}^{2/3} \qquad (3)$$

By combining eq.(1) and eq.(2), the CHF correlation for the two-series-connected duct is derived because of $Q=q_{cr}A_1$.

$$q_{cr}=\frac{1}{A_1\left\{\frac{L_1}{A_1^3}+\frac{(1/k_2)}{A_1^3}\right\}^{1/3}}\left(\int_{T_B}^{T_\lambda} f(T)^{-1}dT\right)^{1/3} \qquad (4)$$

Figure 2 shows the relationship between CHF and A_2/A_1 with bulk temperature as a parameter. The values predicted by eq.(4) are also expressed in term of a curved line. It was confirmed that the CHF correlation could describe the experimental data within 15 % difference.

On the other hand, Pfotenhauer [2] assumed that the heat flow would rapidly expand and became uniform as soon as the heat reached the boundary between the ducts. The values predicted by his assumption are also shown in the figure as a broken line. The values become higher than the experimental data with the increase of A_2/A_1. Although the experimental data are almost constant for A_2/A_1>2.68, the predicted value continues to increase gradually. It is assumed that the heat flow would not rapidly expand to the second duct because of the existence of the vortex near the boundary unlike his assumption.

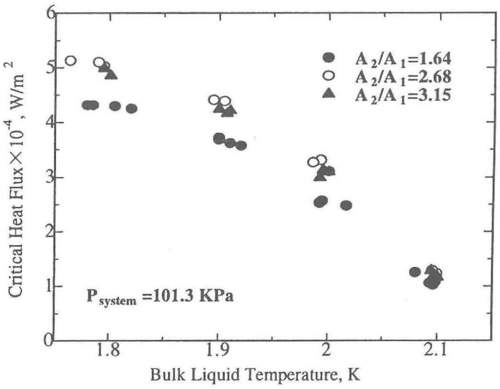

Fig.1 Relationship between CHF and T_B

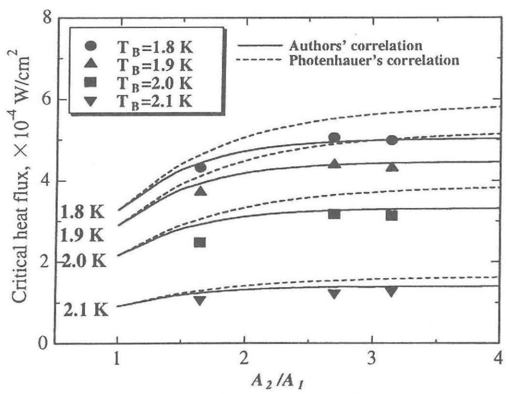

Fig.2 Relationship between CHF and A_2/A_1

References
1) H. Tatsumoto, K. Hata, K. Hama Y. Shirai and M. Shiotsu, Advances in Cryogenics Engineering **45B** (2000) 1073
2) J.M. Pfotenhauer, *Cryogenics.* **32**(1992) 466